Using GPM in an Optimal Estimation Lagrangian Framework (OELaF) to Quantify Moisture Transport in Arctic Cyclones

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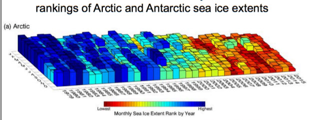
Background

•Since the dawn of the satellite era in the late `1970's, the sea ice in the Arctic Ocean has witnessed a decline extent.

3-D visualizations of the month-by-month rankings of Arctic and Antarctic sea ice extents



New visualizations dramatically display the decreases in Arctic sea ice coverage over the years 1979-2015, apparent in each month of the year, with not a single high in ice extents occurring in any month since 1986, a time period with 75 monthly record lows. Taken from Parkinson and DiGirolamo, 2016

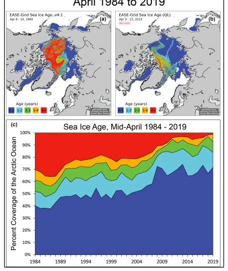
- The majority of the Arctic sea ice is 'young' meaning that It does not survive the summer melt.
- Arctic has become warmer and wetter [Boisvert and Stroeve, 2015]
- Evaporation from the ice-free ocean has been increasing [Boisvert et al., 2015]

What is the 'New Arctic'?

•The Arctic since the early 2000's where large changes have occurred more rapidly in the climate system:

- The sea ice has experienced an increased rate of decline in extent & thickness

Arctic Sea Ice Age Maps Comparing April 1984 to 2019



Arctic sea ice age for (a) April 8 to 14, 1984, and (b) April 9 to 15, 2019. The time series (c) of mid-April sea ice age as a percentage of Arctic Ocean coverage from 1984 to 2019 shows the nearly complete loss of 4+ year old ice. From NSIDC

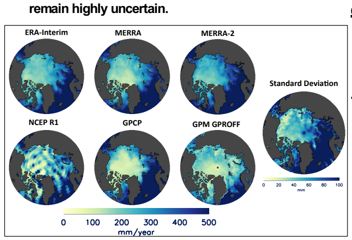
Implications on the Arctic Climate

- ***It is likely, that all aspects of the hydrologic cycle are affected by & also feedback on these large & rapid changes in the 'New Arctic' [Vihma et al., 2016].***
- ***For Example:***
  - Larger moisture gradients between lower and higher latitudes leading to enhanced moisture transport into the Arctic via cyclones [Barnes and Polvani, 2015]
  - Warming temperatures are also associated with a moistening of the atmosphere leading to perhaps more intense P associated with cyclones [Toreti et al.; 2013; Kharin et al., 2013]

Arctic Precipitation

Since cyclones bring a large majority of moisture to the Arctic from lower latitudes [Jakobson and Vihma, 2010], Changes in their frequency & intensity will also impact the hydrologic cycle significantly

- However, **precipitation associated with Arctic cyclones remain highly uncertain.**



Averaged 2014 total precipitation accumulations (mm yr⁻¹) from 4 reanalyses and 2 satellite products. The image on the right shows the standard deviations (mm) between the eight reanalyses. Contour lines are on the color bars.

Observations:

- Lack & difficulty of collecting long term, large-scale observations in the vast, harsh environment
- Issues associated with measuring snowfall.

•Modeling:

- Large uncertainty & spread across P products from reanalyses [Boisvert et al., 2018]
- Lack of knowledge on clouds & the microphysical processes that are unique to the Arctic climate.

A better understanding of Arctic E-P is requisite for closing the local & global, freshwater & energy budgets where large uncertainties remain currently and in the future.

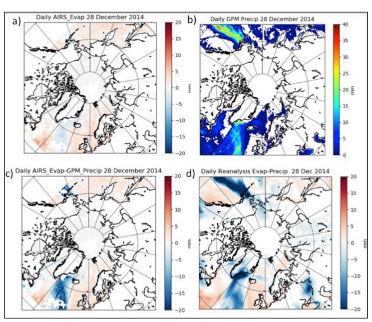
Motivation for our work

•As the New Arctic continues to undergo rapid change observational data of P from GPM (IMERG) and E from AIRS [Boisvert et al., 2013; 2015] can give us critical information on:

- Changes in (E-P) associated with cyclones
- Their effects on the Arctic climate system & moisture processes therein.

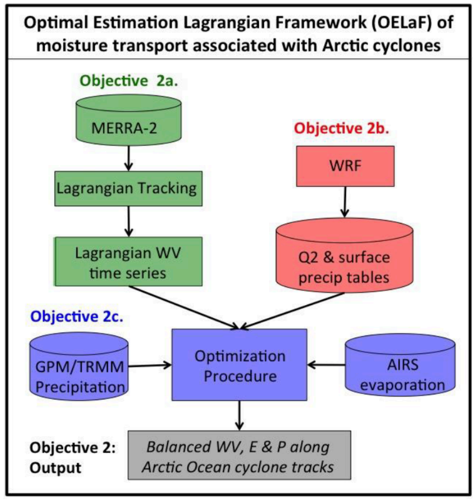
•Process-oriented (E-P) observations can provide invaluable insight into the potential feedbacks of (E-P) changes in the future.

- **Our work aims to improve our understanding of precipitation associated with Arctic cyclones as well as improve our representation of the hydrologic cycle.**

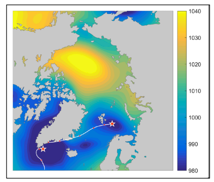


a) Daily E derived using AIRS data. b) Daily GPM surface P estimates over ice-free oceans. The daily estimates are derived by averaging the GPROF daily gridded P estimates from 12 passive sensors. c) AIRS E - GPM P. d) Reanalysis E-P.

- ***Our proposed work aims to track the moisture and precipitation associated with strong Arctic cyclones in order to improve our knowledge of the frequency, intensity and phase of the moisture, how and if it is changing in the New Arctic on an annual, seasonal and regional basis, and how this then in turn affects the sea ice pack.***
- ***In order to achieve this we will:***
  - ***Create a database of strong Arctic cyclone trajectories and Lagrangian track the moisture associated with them using MERRA-2 reanalysis.***
    - ***To balance the moisture budget we will constrain the net precipitation using GPM precipitation and AIRS evaporation data at each time step.***
- ***We propose a novel approach to achieve a more comprehensive, balanced moisture transport associated with Arctic cyclones in an Optimal Estimation and Lagrangian Framework (OELaF).***
  - ***The accuracy of our method will be assessed against in situ measurements.***
  - ***We will then use the balanced moisture transport to conduct multiple physical process studies to gain a better understanding of precipitation, the water cycle, climate, weather and concomitant improvements in numerical models dealing with Arctic cyclones.***



Arctic Cyclone Tracker



Dec. 31, 2014: Location of 2 strong cyclones (stars) with their previous location in 12-hourly timesteps (red dots).

•Using the Melbourne University cyclone tracking scheme [*Simmonds & Murray*, 1999] in a Lagrangian framework

- Computed Laplacian of the SLP fields, local maxima are identified
- Must meet the 'concavity criterion' for 'strong cyclones': Laplacian values of 0.7hpa/degree latitude [*Simmonds et al.*, 2008]
- Tracking follows *Zhang et al.* [2004], distances between timesteps are compared with a location probability distribution map

•6-hourly Sea Level Pressure (SLP) data taken from NASA MERRA-2

AIRS Evaporation

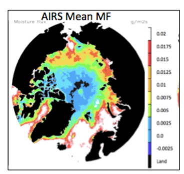
•AIRS is a cross-track high spectral resolution infrared sounder on NASA's Aqua satellite.

•AIRS has daily, global coverage & allows for accurate retrievals under most cloud conditions

- Important in the Arctic where data is sparse and clouds are prevalent.

•AIRS V6 Ts and q data produce accurate estimates in the Arctic when compared to in-situ data

•E is estimated with the bulk-aerodynamic method using MOST and an iterative calculation scheme based on Launiainen and Vihma [1990] with a few modifications tailored to boundary conditions and roughness of sea ice in the Arctic. [Boisvert et al., 2013]



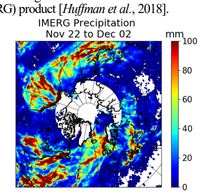
AIRS Mean Evaporation for September 2003-2012. Units are in g/m²s. Positive values are form the surface to atmosphere.

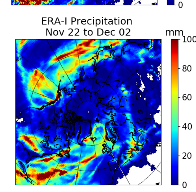
Table of variables used to compute E.

Variable	Unit	Source
Skin Temperature	K	AIRS
1000 hPa Air Temperature	K	AIRS
1000 hPa Relative Humidity	%	AIRS
1000 hPA Geopotential Height	m	AIRS
10 m wind speed	m/s	MERRA-2
Ice Concentration	%	SSMI

GPM Precipitation

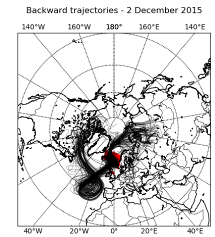
The GPM P estimates used in this project will be provided by the GPM Integrated Multi-satellitE Retrievals for GPM (IMERG) product [*Huffman et al.*, 2018].

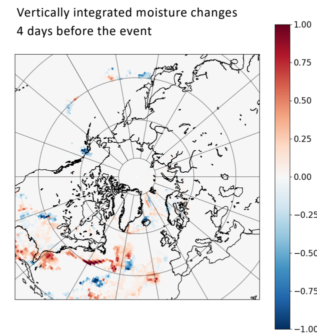


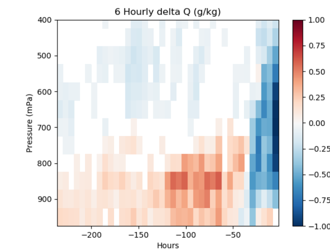


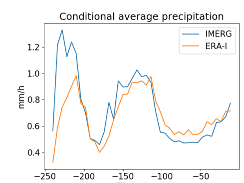
Current Findings

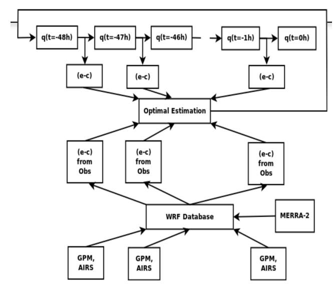
- Half a million particles are integrated backwards starting on Dec, 2 2015.
- Initial locations are specified based on the ERA vertical velocity.
- Moisture changes are gridded as a function of location and time.
- Positive changes are indicative of evaporation processes, while negative changes are indicative of precipitation.
- Conditional average precipitation (e.g. average precipitation at the particle locations) is calculated as a function of time.
- Systematic differences may be suggestive of potential limitations in the reanalysis.











- Conditional average precipitation estimates from reanalysis and IMERG are different for the Dec 2, 2015.
- Systematic differences for a large number of storms for both E and P are likely to indicate deficiencies in the reanalysis.
- Water vapor distributions and the transport will be updated to be consistent with observed E and P.

Future Work

- The methodology above will be applied to a large number of storms
- An evaporation analysis similar to that of the precipitation analysis shown above will be conducted.
- Water vapor analysis and transport will be re-quantified

Acknowledgement

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